

# Analyzing Directional Urban Sprawl from 1978 to 2023 Using Shannon Entropy Analysis on Landsat Imagery: A Case Study in Ramadi City, Iraq

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## Abstract

*The expansion of contemporary cities in developing countries poses a significant challenge for decision-makers involved in urban planning and management. Ramadi, recognized as one of the largest cities in Anbar Governorate and serving as its administrative center, necessitates close monitoring of the changes resulting from urban expansion and the encroachment of its urban sprawl into neighboring areas, a phenomenon referred to as 'urban captivity.' To address this, the study employs Shannon's entropy model, offering a novel approach to examining city expansion using remote sensing data. This research focuses on the urban expansion of Ramadi, utilizing Landsat satellite data spanning four decades (1978, 2000, 2010, 2023). Digital processing and image classification techniques were employed to create four urban maps, enabling the tracking of urban growth patterns over the specified time periods through remote sensing software and geographic information systems. The findings reveal significant shifts in the city's structure, characterized by a notable increase in residential areas accompanied by a significant decrease in agricultural lands. In 1978, agricultural lands within the city's boundaries accounted for 19.99% of the total analyzed area of 139 km<sup>2</sup>, decreasing to 9.17% by 2023. The data also indicates a gradual increase in growth rates from 1978 to 2000, amounting to 0.76, followed by a qualitative surge in urban growth, reaching 5% in 2023. Notably, horizontal urban expansion emerges as the dominant trend over vertical development.*

**Keywords:** Internal Structure, Suburb, Urban Expansion, Urbanization of Villages

## 1. Introduction

In today's world, more than half of the global population lives in urban areas and by 2050, this figure is projected to increase to more than 65% [1]. Based on this projection, 2.5 billion people will add to the world's urban population, trading as Taylor and Francis Group nearly 90% of the urban growth concentrated in less developed countries. Developing countries started the process of urbanization lately, but they are the ones which are rapidly urbanizing [2]. As such, in the past few decades, rapid and often unplanned urban expansion has considerably accelerated more in developing countries than in developed nations [3]. Several studies attributed unprecedented population growth and socioeconomic development as the major drivers of such unplanned urban expansion in most developing countries, urban expansion is recognized as an important phenomenon as it offers increased opportunities for employment, production, and goods

and services [2]. Such increased opportunities in urban areas further enhanced rural–urban migration, as a result, significant urban expansion takes place faster than ever over a short period of time, and in some countries, the space taken-up by urban areas is increasing faster than the urban population itself [4]. Urban captivity is presented as one of the urban development processes associated with the growth of cities, its effects on neighboring areas, especially agricultural ones, and its connection to comprehensive development, which encompasses a wide range of concepts [5]. Here, the process of urban capture of cities should be discussed based on their history and influential factors such as social and economic factors, as well as the strength of administrative authorities in implementing their plans over time during the past century and the present [6].

The expansion of large cities and the growth of spaces within them, witnessed by many countries, result from historical accumulation as a temporal factor in the development of these cities, as well as their location in relation to surrounding lands, whether agricultural or otherwise.

Depending on the definitions of urban land, estimates of the global urban area vary from less than 1–3% of the world's land surface [7]. Despite the fact that urban areas cover a small fraction of the world's land, the rapid urban expansion in different parts of the world has led to significant changes on other land use/land cover (LULC) types. A number of studies reported that urban expansion resulted in encroachment of surrounding landscape such as agricultural lands [8]. From a LULC change perspective, the change induced by urban expansion has considerable effects impacting the environment, ecosystem, and society. These impacts are particularly important in developing countries where there is limited capacity to cope with the environmental and social consequences of rapid urban expansion [9].

Changes in the lifestyle of the population have led to the emergence of new urban areas, especially on the outskirts of cities, where a large segment of people resides, in towns and residential areas adjacent to cities [3]. People living near urban areas are almost entirely influenced by urban lifestyles mixed with rural life, and urban centers are considered employment hubs for non-agricultural activities, including industry, services, and trade.

Over time, cities have also been regarded as centers of cultural, social, and intellectual development, with urban growth being a process resulting from the emergence of a world dominated by cities [10]. It is crucial to distinguish between two main processes: urbanization and the invasion of cities into their neighboring areas under the name of urban captivity, and urban expansion adopted by administrative authorities to relieve congestion in the city center. There are interesting and related cases of urban sprawl resulting from population growth [11]. The administrative authority often neglects to determine the direction of this growth. This study focuses on the city of Ramadi, one of the cities in Iraq affiliated with Anbar Governorate, aiming to investigate areas affected by urban captivity by analyzing satellite images taken in the last quarter of the last century and the current century. This study can help better understand the dynamics and spatial pattern of urban growth and provide pertinent information to devise proper urban planning and management policy directions for sustainable future urban development with minimal associated impact.

## 2. Methodology

### 2.1 Study Area

The study area encompasses the city of Ramadi, notable for its location along the Euphrates River [12]. According to the fundamental design [13], it is situated astronomically between latitudes  $33^{\circ}23'33''$  and  $33^{\circ}27'00''$  north, and longitudes  $43^{\circ}09'00''$  and  $43^{\circ}22'00''$  east as show in Figure 1.

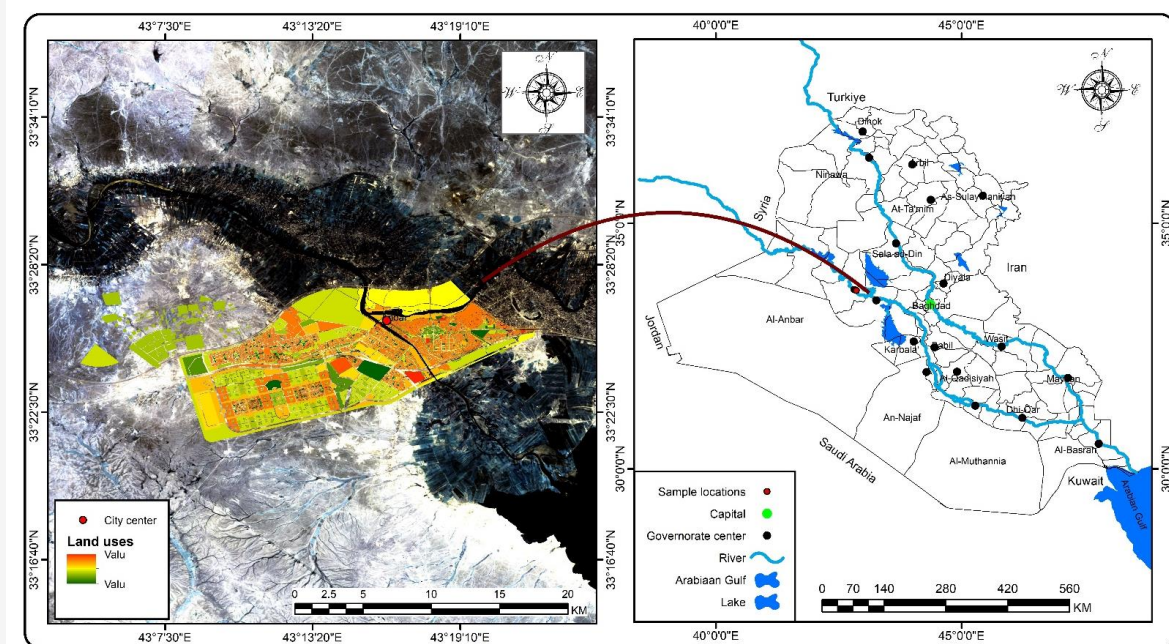


Figure 1: Ramadi city, Anbar Governorate, Iraq

## 2.2 Data and Work Approach

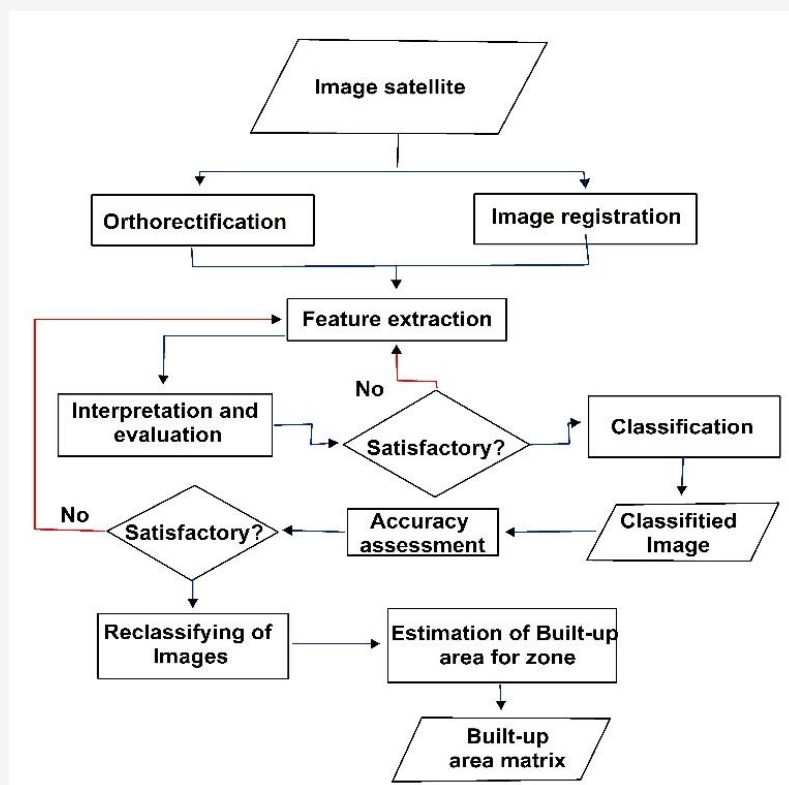
Understanding the dynamic phenomenon of urban consolidation necessitates defining urban areas and sprawl patterns, calculating natural area parameters, and analyzing changes in built-up areas [13]. Determining changes in the area integrated into urban zones is crucial for urban planning, management, and environmental research [14]. For this study, topographic maps at a scale of 1:100,000 for the purpose of determining the boundaries of the city's municipal borders according to what was stated by the official authorities, basic design maps of Ramadi city, and Landsat satellite images from the years 1978, 2000, 2010, and 2023 were acquired.

The frequency and periods of all satellite data and supporting data used in this study are summarized in Table 1. The methodology flowchart is presented in Figure 2. The Landsat images were projected to the UTM-WGS-84 coordinate system, Zone 38 North.

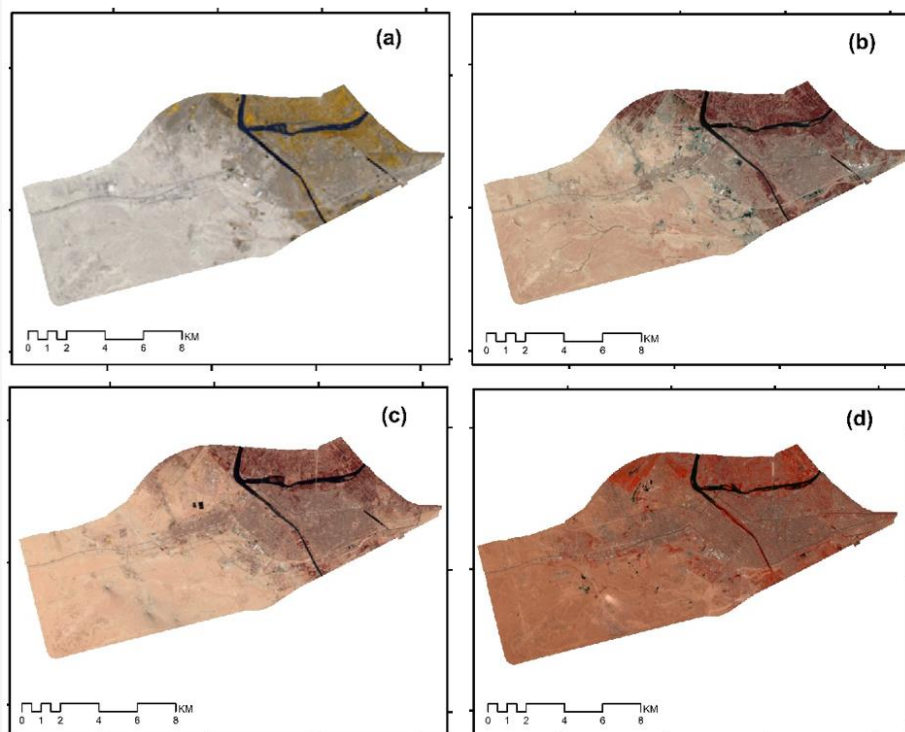
Parts of the satellite images were cropped in each of the spectral bands utilized, with the cropped sections representing the targeted study area: the borders and suburbs of Ramadi city. In the subsequent step, the cropped spectral bands were merged to generate three new composite visualizations of the study area, as depicted in Figure 3.

**Table 1:** Landsat satellite image data for the study area

Years	Landsat series	Acquisition dates	Path /Row	Bands
1978	Landsat 2MSS	1978/02/03	183/37	1, 2, 3
2000	Landsat 5TM	2000/01/19	169/37	1, 2, 3
2010	Landsat 5TM	2010/02/15	169/37	1, 2, 3
2023	Landsat 9 OLI	2023/07/21	169/37	2, 3, 4, 5



**Figure 2:** Urban expansion study workflow



**Figure 3:** Shows the merged images for the years: (a) 1978, (b) 2000, (c) 2010, and (d) 2023

Color composite images are a specialized method in digital processing that enhances visualization, enabling the inference of new information and providing better guidance for the classification and identification of features and land covers [15]. The resulting product underwent testing through the creation of concentric circles encompassing the entire study area from the city center (the nucleus of the formation). These circles were drawn to include areas within a 500-meter radius from each other [16], spanning various geographical directions. This segmentation was implemented to facilitate a statistical comparison of variables related to building expansion in different directions. It's worth noting that the radius of each circle must be sufficiently large to encompass all urban boundaries and the lands within them [17].

The structure of urban boundaries undergoes dynamic changes in various directions over time. However, this study focuses on examining the period during which the most significant expansion of Ramadi city's boundaries occurred, utilizing Shannon's entropy model. Widely employed in urban sprawl studies, this method serves as an indicator of spatial concentration or distribution and can be applied to any geographical variable through integration with remote sensing and geographic

information systems. The Shannon entropy ( $H_n$ ) is defined in Equation 1 [18].

$$H_n = -\sum_{i=1}^n p_i \cdot \log_e(p_i)$$

Equation 1

Where:

$P_i$  is the probability of the variable occurring the  $i^{th}$  zone

$n$  is the total zone number

It signifies that the distribution of built-up areas is compact, indicating a concentration in a specific location and a preference for vertical expansion over horizontal expansion. Conversely, values approaching 1 indicate a greater horizontal expansion, signifying a dispersed distribution of built-up areas. A value of zero also implies a compact distribution of buildings, whereas values nearing 1 suggest a more scattered distribution of built-up areas. Additionally, higher values of this indicator signify urban sprawl within the city, often at the expense of neighboring areas. Should the values of this indicator surpass the threshold value of 0.5, often referred to as the halfway mark, it is generally considered a significant threshold. This indicates that the city's expansion extends beyond its core, potentially into peripheral areas.

Establishing a lower bound for this measure is essential for robust analysis and can be applied to any area under study.

The calculation of the phenomenon relies on a specific LULC classification algorithm, Maximum Likelihood Classification, which performs maximum likelihood classification on a set of grid ranges and creates a classified grid as the final output, i.e. a file generated by the signature generation or signature editing tools is a valid input to the input signature file. By default, all cells in the resulting raster grid will be classified, with equal probability weights attached to each class with their signatures. The input prior probability file must be an ASCII file consisting of two columns. The values in the left column represent the class identifiers. The values in the right column represent the prior probabilities of the respective classes. Valid values for the prior class probabilities must be greater than or equal to zero. If zero is specified as the probability, the class will not appear in the resulting raster grid. The sum of the specified prior probabilities must be less than or equal to one.

Random forest classifiers and their working mechanism and support trends in GIS have been implemented and these algorithms (classifiers) have been evaluated through statistics, and the support vector machine (SVM) is used for classification as well as for regression analysis [19]. The SVM algorithm generates the best decision line or boundary (or hyperplane) that separates the space into classes so that new data can be easily placed in the correct class. The SVM then selects the extreme points that help in creating the hyperplane Figure 4. Its goal is to maximize the margin between classes. The linear support vector machine is a standard

model, and Equation 2 is used to evaluate the overall accuracy (OA) of LULC classification. The change in land use is calculated taking into account the temporal land uses based on the base year (1978) and year (2023) data [20].

$$OA = \frac{TP}{TT} \times 100$$

Equation 2

Where:

*TP* is numbers of correct classified feature

*TT* is total number of features

There are several ways that can be used to specify a subset of domains from a multi-domain network to use as input to the tool. If the class name in the signature file is different from the class ID, an additional field called is added to the attribute table of the output network. For each class in the output table, this field will contain the class name associated with the class. For example, if the class names for the classes in the signature file are descriptive string names (e.g., conifers, water, urban), these names will be moved to the class name field. The values of urban growth rates are identified by Equation 3 [20].

$$K = \left( \frac{U_b - U_a}{U_a} \right) \times \frac{1}{T} \times 100$$

Equation 3

Where: *K* = annual urban growth percentage rate, while *U<sub>a</sub>* and *U<sub>b</sub>* represent the urban area at the beginning and end of the monitoring period, respectively and *T* is the time period from time *a* to *b*.

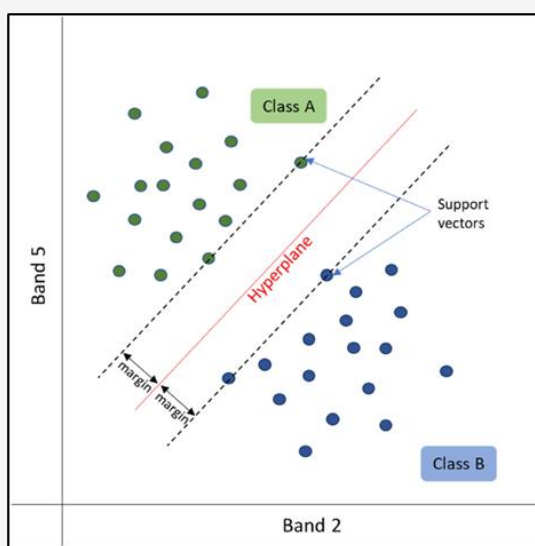


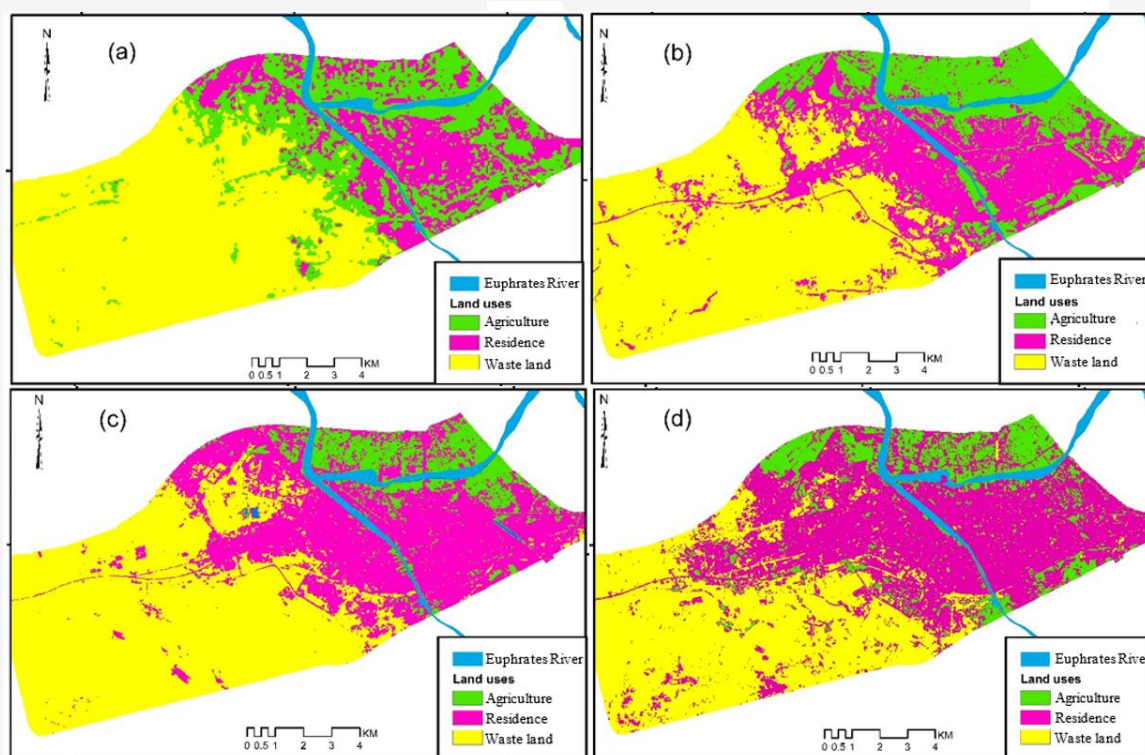
Figure 4 Support vector machine

### 3. Results and Discussion

Figure 5 illustrates the outcomes of the supervised classification conducted using the aforementioned satellite images for the years 1978, 2000, 2010, and 2023, respectively. The ArcGIS 10.8 program was employed, utilizing a random sampling method to ensure the highest accuracy. Directed classification was also implemented. A total of 230 pixels were meticulously selected and scrutinized through on-site inspections and the examination of high-resolution images provided by Google Earth. The results revealed that the urban expansion of the city of Ramadi encroached upon the agricultural lands situated on its periphery, as delineated in Table 2. The overall accuracy results indicate that the analyzed images closely matched the reality observed in the field, with an approximate accuracy rate of

91%. This is for the year 2023, while the accuracy of the results for the year 2010 reached 93%, while in the year 2000 and the year 1978 it ranged between (89 - 90%), as shown in Table 3.

This confirms the effectiveness of the image processing approach utilized in this study in generating reliable urban land use data over time. The land use in the city of Ramadi can be categorized into three main groups. The sequential analysis of the images revealed that urban development has encroached upon the agricultural lands adjacent to the city's urban core. Additionally, there has been an expansion into wastelands. In 1978, agricultural lands within the city's designated area constituted 19.99% of the total analyzed area of 139 km<sup>2</sup>.



**Figure 5:** Distribution of land uses for the basic design of the city of Ramadi for the years: (a)1978, (b) 2000, (c) 2010, (d) 2023

**Table 2:** Areas of land cover types in the city of Ramadi from 1978 to 2023

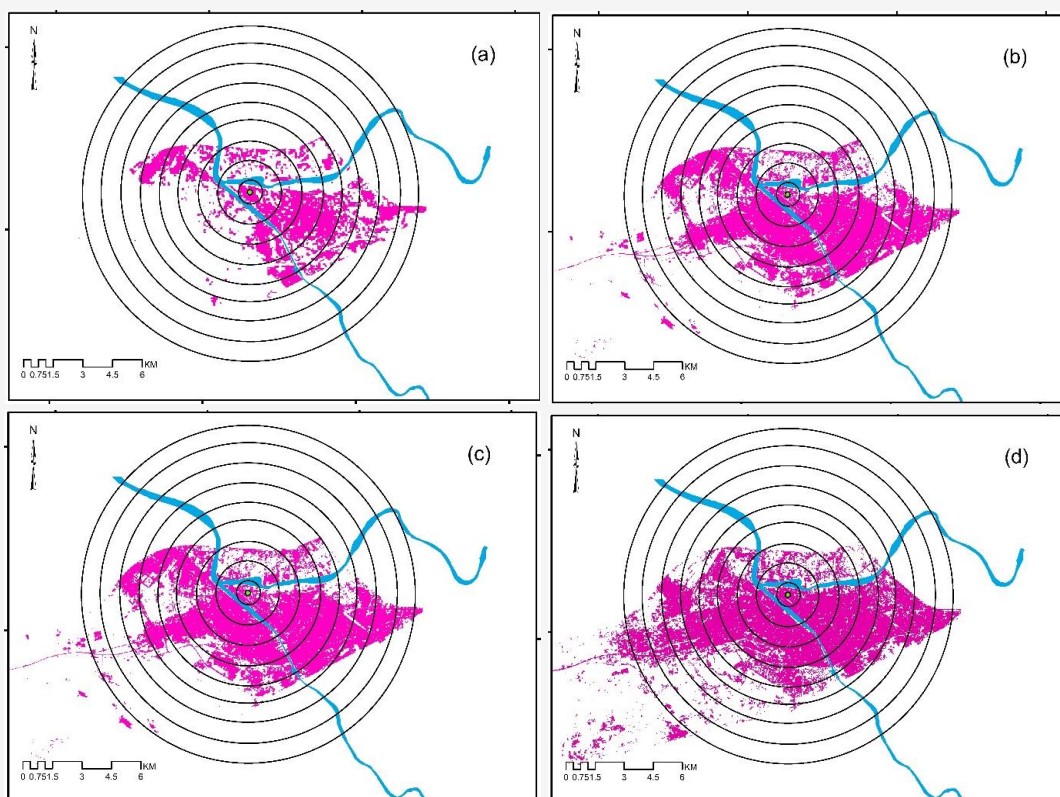
Land cover type	Area in km <sup>2</sup> [%]			
	1978	2000	2010	2023
Agricultural	27.79 [19.99]	19.68 [14.15]	16.61 [11.94]	12.75 [9.17]
Residential	25.64 [18.44]	42.45 [30.53]	49.57 [35.66]	71.30 [51.29]
Waste land	85.57 [61.56]	76.87 [55.30]	72.82 [52.38]	54.95 [39.51]

**Table 3:** The overall approximate accuracy rate of the classification results for the specified four years

Year	1978	2000	2010	2023
OA (%)	89	90	93	91

**Table 4:** Shannon's entropy and changes in entropy between city of Ramadi (1978 - 2023)

Year	Urban Block Area (%)	Shannon's Entropy
1978	25.64	0.58
2000	42.45	0.73
2010	49.57	0.83
2023	71.30	0.87

**Figure 6:** Division of built-up area into concentric circles with radius of 1 km interval: (a)1978, (b) 2000, (c) 2010, (d) 2023

However, by 2023, this figure had decreased to 9.17%. This decline can be attributed to the expansion towards the north and east of the city, where agricultural lands are situated. Although this expansion also encroached upon wastelands, the proportion of residential areas increased significantly from 18.44% in 1978 to 51.29% in 2023. This illustrates the substantial growth and expansion of the urban area of Ramadi over the course of 43 years.

### 3.1 The Analysis of Urban Growth in Ramadi from 1978 to 2023

For the inner core circles Figure 6, the relative Shannon's entropy decreased from 0.17 in 1984 to 0.09 and 0.14 in 2014 for first two zones. This showed the presence of infill or intensification, which indicated the increasing density of built-up areas within the first km<sup>2</sup> radius. However, a general increasing trend in entropy values was observed for the outer seven zones indicating more dispersion of built-up areas. The relative Shannon's entropy values in 1978, 2000, 2010, and 2023 were, 0.58, 0.73, 0.83, and 0.87, respectively Table 4.

Relatively lower value of Shannon's entropy in 1984 indicated the compact and homogeneous distribution of the built-up areas; whereas the increasing trend of entropy values between 1984 and 2014 demonstrated a high rate of urban sprawl as a result of dispersed urban growth spreading over the urban fringe. Furthermore, the positive values of the changes in entropy indicated that urban expansion is towards a more dispersed pattern [17].

#### 4. Conclusion

To map surface changes in the city of Ramadi and monitor urban expansion over the past forty-three years, urban land use maps have been produced, which categorize three main land use types. Using a supervised classification scheme for Landsat images from 1978 to 2023, it was observed that the urban area expanded from 25.64 to 71.30 km<sup>2</sup>, with a growth rate ranging from 0.76% to 5%. This expansion occurred primarily at the expense of wastelands and agricultural lands, particularly in the eastern and northern regions of the city. These figures highlight the phenomenon of urban encroachment practiced by the city at the cost of its neighboring lands. Despite plans to steer urban growth westward towards barren plateaus, away from agriculturally significant areas with crucial economic and environmental benefits, the period from 2010 to 2023 saw an unprecedented surge in urban expansion. This growth surpassed even the cumulative growth observed from 1978 to 2000, signifying a shift towards horizontal urban expansion as the predominant trend over vertical expansion. Pressure on the capacity of the regional and local authorities to provide better infrastructure and basic public amenities. It is, therefore, important to enforce timely and appropriate land use planning which considers the requirements of social, economic and environmentally sustainable development. In addition, for effective implementation of policies and strategies, the extent and rate of urban land use dynamics and its multitude impacts should be well understood by all stakeholder including planners, policy makers, environmentalists and people in general. The results of this study provide baseline information to better understand the current status of urban growth as well as to devise comprehensive and up-to-date urban planning and development policies to assure sustainable urban development. Further this study demonstrates that integrating satellite remote-sensing data and spatial metrics provides a powerful and effective means to visualize changes in LULC and spatial pattern of urban expansion.

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